High Noncondensible Gas Liquid Dominated Geothermal Reservoir, Kizildere, Turkey

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ABSTRACT

Noncondensible gas in the Kizildere geothermal reservoir is 99% carbon dioxide (CO_2). CO_2 concentrations dissolved in the geothermal reservoir brine vary from 0.02-0.03 kg/kg of brine in the deep >225ºC reservoir and 0.01-0.02 kg/kg of brine in the intermediate <200ºC reservoir. The partial pressure of CO_2 at the top of the deep reservoir is greater than 50% of the total reservoir pressure. While the presence of marble within the reservoir indicates that the source of CO_2 may be thermal decomposition of carbonates, decarbonisation by reaction of carbonates with alumina silicates may also contribute to the concentration of CO_2 in the reservoir brine.

The dissolved CO_2 in Kizildere is of sufficient concentration to affect the behaviour of the fluids, specifically the transition to two-phase conditions. As pressure is released or temperature decreases, dissolved CO_2 decreases and calcium carbonate precipitates. Specifically, this transition to two-phase and/or cooler conditions may decrease the effective permeability of the cap rock and thus increase the separation between reservoir zones. The depth at which gas breakout occurs is deep into the reservoir at the approximate depth of the impermeable section between the two reservoirs.

Introduction

The Kizildere Geothermal Reservoir was discovered in 1968 when well KD-1 was completed to approximately 520 meters (m) and encountered 198ºC geothermal fluid by the Turkish government agency (MTA). Geological, geochemical and geophysical investigations, temperature gradient holes, approximately 20 deep wells were completed to characterize and develop the resourse. In 1984, power generation began at a 15-20MW power plant, Kizildere I, the first geothermal power generation in Turkey.

In 2008, Zorlu Energy Group (Zorlu) acquired the Kizildere field and began resource investigations and drilling to supply a 60 MW expansion. The data used in this work were developed by Zorlu as part of the testing of wells recently drilled to supply the new plant.

The Kizildere Geothermal Reservoir is located at the eastern end of an east-west trending extensional tectonic valley known as the Büyük Menderes Graben (Şimşek, 1985). The Paleozoic Menderes Metamorphic rocks that outcrop in the horst regions north and south of the reservoir area are downthrown along a series of semi-parallel east-west trending normal faults within the graben forming the basement rock, which are overlain by Tertiary sediments and alluvium. The Menderes Metamorphics form the main reservoir rocks.

The geothermal reservoir is a fractured reservoir. These semi-parallel east-west trending normal faults parallel to the graben and that cut formations from the Tertiary to the Palaeozoic provide potential conduits for upflowing hot water at Kizildere as well as in other geothermal reservoirs related to grabens in the Aegean Extensional Province (Ciftci and Bozkurt, 2009). These graben-oriented faults appear to be cut by a second set of north-south trending faults in the immediate vicinity of the Kizildere reservoir.
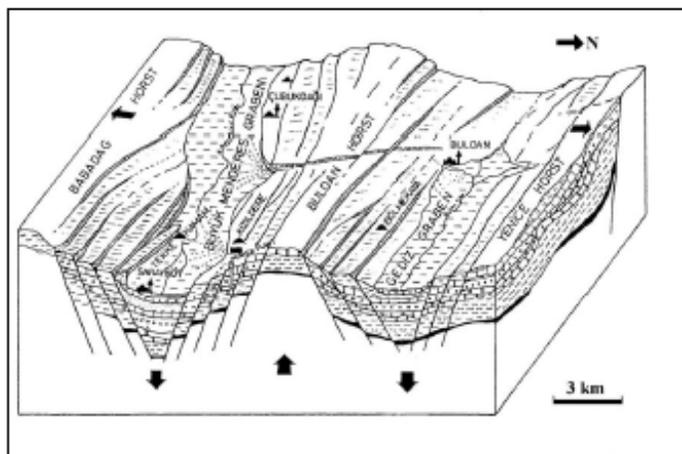
Figure 1. Buyuk Menderes Graben after Simsek, 1985.

Recent seismic activity suggests that the area is tectonically active and is extending in the north-south direction (Simsek, 2003) and therefore the faults have the potential to be open and permeable.

Deep production zones at Kizildere are primarily encountered in the brittle limestone, marl, marbles, quartzite and gneiss of the Paleozoic Menderes metamorphic rocks, as in other geothermal systems related to Aegean grabens (Tarcan et al., 2000). Layers within the metamorphics with higher clay (including metamorphic mica) provide impermeable caps to the upwelling geothermal fluid in the permeable reservoir zones hosted in more brittle formations. It appears that production zones occur at the intersection of fractures and brittle rocks.

The heat source for the geothermal system is related to the high heat flow of extensional tectonic regimes such as the Menderes Graben. Magmatic contributions to geothermal fluids have been suggested, but there are no young volcanic formations in the vicinity of the Kizildere Geothermal field.

Reservoir Characteristics

The Kizildere Geothermal Reservoir is layered into shallow, intermediate and deep zones (Simsek, 2003). The shallow zone occurs in discontinuous Tertiary limestones and marls (Sazak formation) in the upper 500m.

The intermediate reservoir occurs within the marbles and quartzites in the upper section of the Paleozoic rocks (Igdecik formation, upper boundary between 500-1400m) and the deep reservoir occurs in brittle sections of quartzites, gneiss and marble within the Paleozoic Menderes Metamorphic rocks below approximately 1200 to 1400m, deepening towards the center of the graben and on the eastern and western portions of the field.

Consistent with the structural control of the resource, not all sections are present in all parts of the field nor do they occur in constant thickness or depths. Permeable geothermal fluid-bearing layers within these brittle sections of rock are overlain by impermeable sections of schist (Paleozoic) or clay (Tertiary).

Only wells completed in the intermediate and deep reservoirs are (or are intended to be) used for production. The intermediate reservoir wells are currently producing to the existing Kizildere I plant and the deep reservoir wells are intended to produce to Kizildere II plant. In addition to approximate depths, noncondensible gas data from these wells also distinguishes the two reservoirs. As shown in Table 1, total nonconcensible gas concentrations in

the deep reservoir (average 0.032 kg NCG/kg of reservoir brine or approximately 3.2 weight%) are almost twice those in the intermediate reservoir (average 0.014 kg NCG/kg brine or approximately 1.4 weight %). However the composition of gas is almost identical with 99 mole% CO_2. The difference in total dissolved solids is almost entirely due to differences in dissolved carbonate.

Calcite Equilibrium and CO_2 Concentrations

Given the predominance of limestone and marble in the Kizildere reservoir host rocks, it is not surprising that CO_2 is prevalent in reservoir fluids as a result of calcite dissolution. CO_2 could be generated by the following reactions:

$$CaCO_3 + H_2CO_3 = Ca^{+2} + 2HCO_3^{-1} \quad (1)$$

where

$$CO_2 + H_2O = H_2CO_3 \text{ (dissolved } CO_2) \ (2)$$

and

$$HCO_3^{-1} + H^+ = H_2CO_3, \text{ (dissolved } CO_2) \ (3)$$

and

$$CaCO_3 + H^+ = Ca^{+2} + HCO_3^{-1} \quad (4)$$
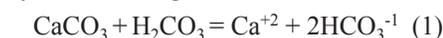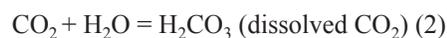
The precipitation and dissolution of calcite ($CaCO_3$) can produce variable amounts of dissolved CO_2 depending on temperature and pH based on reactions 1-4 (Drever, 1988; Ellis, 1963).
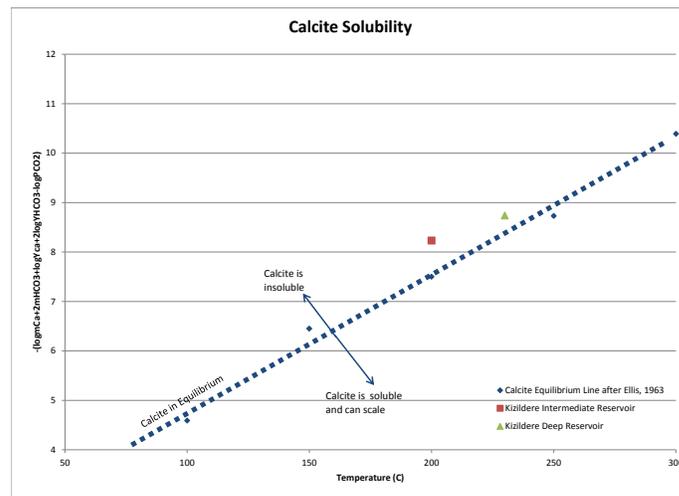
Figure 2. Calcite Solubility in the Intermediate and Deep Reservoirs.

Table 1. Average Noncondensible Gas Concentrations, TDS, Depth to Gas Breakout and Gas and Total Pressures in the Reservoir.

Kizildere Reservoir Layer	NCG in reservoir	CO2	H2S	N2	CH4	Ar	H2	He	NH3
	kg/kg	m%	m%	m%	m%	m%	m%	m%	m%
Deep	0.032	98.82	0.026	0.52	0.38	0.08	0.002	0.000	0.26
Intermediate	0.015	98.96	0.005	0.57	0.44		0.003		0.09
	TDS in reservoir	Depth to Gas Breakout	Depth to top of reservoir	Total Pressure Ptot	Gas Pressure PCO2				
	mg/kg	m	m	bara	bara				
Deep	4700	1200-1800	>1600	100-160	67-85				
Intermediate	3500	300-600	400-1000	40-60	17-36				

Under otherwise constant conditions, higher concentrations of dissolved CO_2 (reaction 2) pushes reaction 1 to the right and dissolves calcite increasing bicarbonate and calcium in the reservoir liquid. In contrast, when, lower pressures decrease the solubility of dissolved CO_2 relative to CO_2, calcite precipitates. The precipitation of calcite as a result of depressurization during production at Kizildere (Satman et al., 1999) is well documented although it is currently control with scale inhibitors (Tut Haklidir et al., 2011).

As in many geothermal systems, both intermediate and deep reservoir fluids are in equilibrium with calcite (Figure 2). Since calcite solubility is inversely related to temperature, higher temperatures push reaction 1 to the left, increasing the formation of dissolved CO_2, as long as the system doesn't depressurize.

The correlation of dissolved CO_2 and temperature in reservoir fluids (Figure 3) is consistent with more vigorous calcite dissolution at higher temperatures. In addition, the dissolution of calcite in the presence of free acid may promote the high dissolved CO_2 in dynamic conditions as the water-rock system attempts to equilibrate. A few carbon isotope analyses available from Kizildere deep reservoir noncondensible gas samples ($\partial^{13}C$=0.17-0.07 $°/_{oo}$)
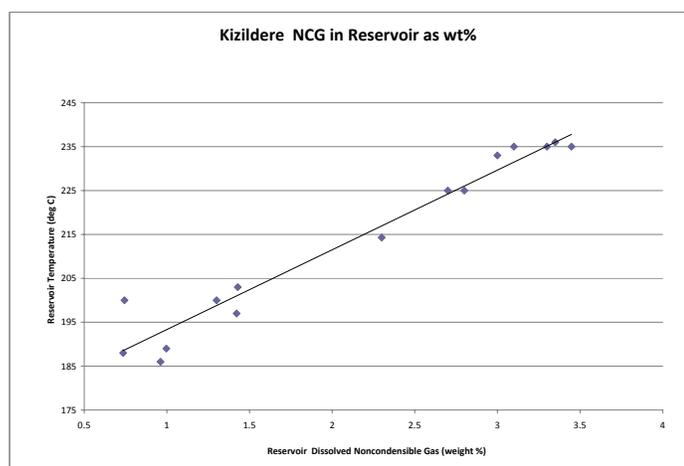
Figure 3. Total Dissolved Noncondensible Gas (99% CO_2) in Kizildere versus Reservoir Temperature.
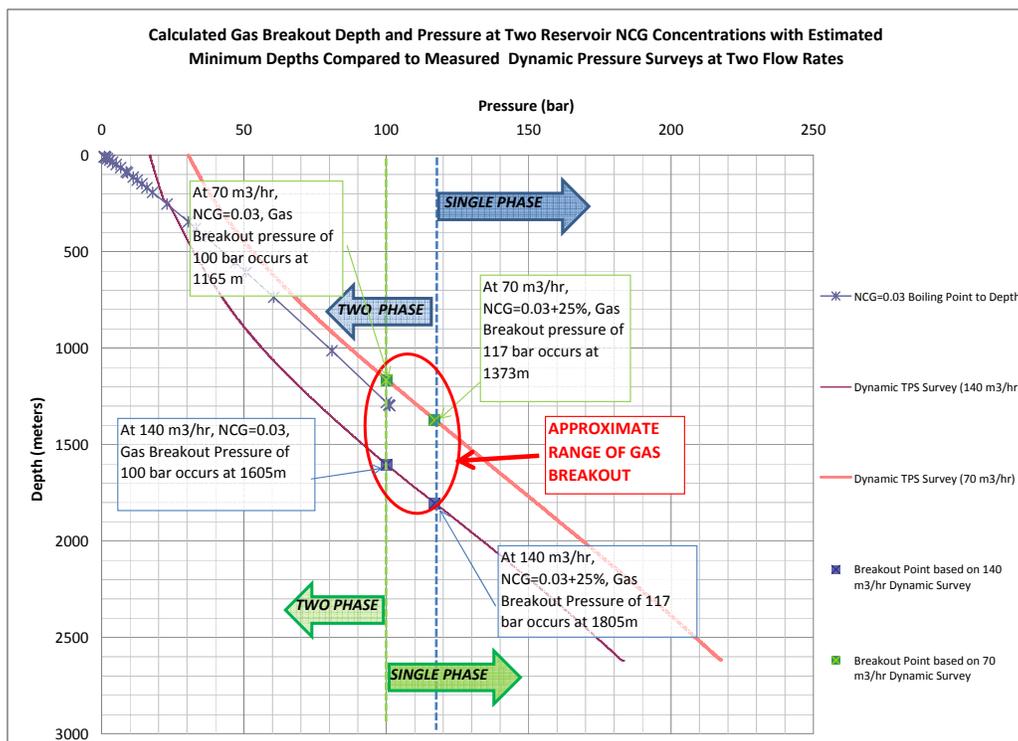
are consistent with carbonate origin for the CO_2 in Kizildere geothermal fluids.

Dissolved Gas Concentrations and Depth to Gas Breakout (Calcite Scaling Depth)

The higher concentrations in the deeper reservoir produce significantly higher total reservoir pressures (Table 1). The differences between the total pressures in the intermediate and deep reservoirs as well as the differences in CO_2 concentrations and pressures (P_{CO2}) suggest limited interaction between the two reservoir layers and therefore a possible permeability barrier between them.

Kizildere fluids precipitate calcite scale at the point of degassing (Satman et al., 1999). The depth that degassing occurs is dependent on the CO_2, reservoir pressures and temperatures. Higher CO_2 concentrations also cause degassing to occur at greater depths (Table 1). Depths to degassing are calculated using Henry's law to estimate gas pressure, steam tables to estimate water pressure and estimated depths in accordance with Henley et al. (1984), as shown in Figure 4 for a typical deep reservoir well. The estimated depths to gas breakout are then compared with pressures from dynamic well pressure-temperature surveys to obtain a range of depths where gas breakout can be expected. When the measured gas concentration varies and flow rates also vary (dynamic surveys are performed over a range of flow rates), the range of depths to gas breakout can be large. The depth to gas breakout is equivalent to the maximum depth that calcite scaling could be expected in a flowing well, depending on flow rate and gas concentration. As shown in Figure 4, the depth to gas breakout is dependent on the flow rate, but the depths are typically between the intermediate and deep reservoirs (Table 1).

If tectonic activity caused the Kizildere system to vent at some time in the past, the boiling point for the deep and intermediate reservoir would occur at and above the top of the deep reservoir. Since calcite would be expected to deposit at the depth of degassing, it is possible that the impermeability of the reservoir cap in Kizildere is augmented by calcite precipitation. However, if such venting occurred, the reservoir fluids have re-equilibrated as reservoir dissolved CO_2, $Ca^{+2} + 2HCO_3^{-1}$.

Conclusions

The Kizildere geothermal reservoir is characterized by distinct layers. The intermediate and deep layers are distinguished by temperature and dissolved CO_2 concentrations. The dissolved gas appears to be related to the dissolution of calcium carbonate. Gas

Figure 4. Estimated Depth to Gas Breakout at two different reservoir gas compositions: 0.03 and 0.0375 kg/kg NCG in reservoir brine. Dynamic pressure surveys performed at two flow rates (70 and 140 t/h).

concentrations in the reservoir correlate with temperatures, indicating a relationship between calcite dissolution and temperature. In addition, the effect of different concentrations of dissolved CO_2 on the gas breakout depth and thus the depth that scaling occurs on depressurization may contribute to the formation of separate reservoir layers by precipitation of calcite at different depths.

Acknowledgements

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